TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 195

ON THE DISTRIBUTION OF LIFT ALONG THE SPAN OF AN AIRFOIL WITH DISPLACED AILERONS.

By Max M. Munk.

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Summary

The effect of an aileron displacement on the distribution of the lift along the span is computed for an elliptic wing of aspect ratio 6 for three conditions.

The lift distribution caused by the aileron displacement is uniform and extends normally beyond the inner end of the ailerons. Hence, the displacement of an aileron with constant chord length may bring about passing the stalling point of the adjacent wing sections, if these were near this point before. Hence, such ailerons can become ineffective at low speeds.

Tapering the aileron towards the inside suggests itself as a remedy.

Reference

Max M. Munk: Elements of the Wing Theory and of the Wing Section Theory - N.A.C.A. T.R. No.191.

The computations laid down in the following paper refer primarily to the problem of lateral control of airplanes at low flying speeds as affected by the ailerons. The ailerons may then become ineffective or their action may be reversed. If the airplane is flying beyond its stalling speed, this would not be surprising. The displacement of the ailerons must be considered as a change of the wing sections near the wing ends, increasing or decreasing the effective camber of the section. When flying beyond its stalling speed, the effect of such a change of section cannot be generally predicted, but depends entirely upon details of the wing and wing section shape and upon the conditions of flight. There is still sufficient information lacking for a useful discussion of this case.

But even if the critical angle of attack has not yet been passed, and if the flow around the wing is only near the burble point, displacing of the ailerons sometimes gives rise to passing that point. Now, as a general rule, turning the aileron down and thus increasing the effective camber and angle of attack, increases the critical lift coefficient in such a way that the airflow remains below the burbling limit. The loss of control in such cases is therefore surprising. The following computations are made to find the explanation and the remedy.

Under the usual assumptions underlying the wing theory and wing section theory, the distribution of the lift over the span is a linear function of the angle of attack at each point of the span. It is, therefore, permissible to compute the lift distribution caused by the displacement of the ailerons only, and to superpose it afterwards on the distribution of lift for the neutral position of the ailerons. The same remark holds true with the obtained effective angle of attack.

Further, the change of the wing section brought about by the displacement of the ailerons, in respect to the present problem, is equivalent to a change of the geometric angle of attack. Otherwise spoken, a twist of the wing-ends in a particular way, in accord with the dimensions of the wing-ends and of the ailerons, can be substituted for the change of section which actually takes place.

Let the wing be elliptical, and the aspect ratio be $\frac{S}{b^2} = \frac{1}{6}$ in the numerical part of the computation. The distance x of a wing element from the middle of the wing may be expressed by the angle δ by means of $x = \frac{b}{2} \cos \delta$, (Fig. 1). The effect of turning the aileron down (or up) is now assumed to be equivalent to the addition (or subtraction) of a constant geometric angle of attack, which may be denoted by α_o. This assumption requires a constant ratio of the wing chord to the aileron chord. Hence, we consider the case of an elliptic wing, the geometric angle of attack of which is $\alpha = \alpha_o$ between the end $\delta = 0$ and the inside end of the aileron, $\delta = \beta$; and the angle is $\alpha = 0$ between the two inside aileron ends $\delta = \beta$ and $\delta = 180^\circ - \delta$, and the angle is $\alpha = - \alpha_o$ along the second aileron extending from $\delta = 180^\circ - \delta$ to $\delta = 180^\circ$.

The method of computation used is explained in the paper referred to. The first step consists in expanding $\alpha \sin \delta$ into a

Fourier's series.

(1) $\alpha \sin \delta = A_1 \sin \delta + A_2 \sin 2\delta + \dots A_n \sin n\delta \dots +$

Since in the present case the function to be expanded is odd with respect to the middle of the wing, $\delta = 90^\circ$, all odd coefficients, A_1, A_3, etc., become zero and there remains

(2) $\alpha \sin \delta = A_2 \sin 2\delta + A_4 \sin 4\delta + \dots + A_n \sin n\delta + \dots$ (n even).

The value of A_n is obtained from the integral

(3) $A = \frac{2}{\pi} \int_0^\pi \alpha \sin \delta \sin n\delta \, d\delta$

This becomes in this case

(4) $A_n = \frac{4}{\pi} \alpha \int_0^\beta \sin n\delta \, d\delta = \frac{2}{\pi} \alpha_o \left(\frac{\sin(n-1)\beta}{n-1} - \frac{\sin(n+1)\beta}{n+1} \right)$ (n even)

For the computation of A_n it is convenient, first to compute $\frac{\sin(n-1)\beta}{n-1}$ which may be denoted by C_n.

(5) and from this first $\frac{A_n \frac{\pi}{2}}{\alpha_o} = B_n = C_n - C_{(n+2)}$

The effective angle of attack is shown in the reference to be

(6) $\alpha_e = \frac{1}{\sin \delta} \left[\frac{A_1 \sin \delta}{1 + \frac{2S}{b^2}} + \frac{A_2 \sin 2\delta}{1 + \frac{4S}{b^2}} \dots \frac{A_n \sin n\delta}{1 + \frac{2nS}{b^2}} \right]$

Hence the next step is dividing the B_n by $\left(1 + \frac{2nS}{b^2}\right)$. The result may be denoted by F_n.

(7) $F_n = \frac{B_n}{1 + \frac{2nS}{b^2}} = \frac{\frac{\sin(n-1)\beta}{n-1} - \frac{\sin(n+1)\beta}{n+1}}{1 + \frac{2nS}{b^2}}$, n even.

Equation (6) can then be written

$$\frac{\alpha_e}{\alpha_o} = \frac{2}{\pi}\left[F_2 \sin 2\delta + F_4 \sin 4\delta \ \ldots\ F_n \sin n\delta\right] + \ldots .$$

I have performed this computation for the cases $\frac{b^2}{S} = 6$, $\beta = 30^\circ$, and $\beta = 60^\circ$.

The terms for values of n larger than $n = 16$ are neglected which is permissible as the final results are chiefly used for illustration, and the exact numerical result less valuable.

The results are plotted in Figs. 2 and 3. The dotted line represents the equivalent geometric angle of attack, the heavy line the effective angle of attack in the same scale. The light line represents the density of lift per unit length of span in an arbitrary scale as it depends upon the velocity of flight and the density of air. Its magnitude is under the usual assumptions

$$L' = \alpha_e\, 2\,\pi \times \text{chord} \times V^2\, \frac{\pi}{2}$$

It is generally known that the air forces produced by a displacement of the ailerons act mainly on the immovable portion of the wings. But it is often thought that these air forces are concentrated at the wing portions in front of the ailerons. Figs. 2 and 3 show that such is not the case. The wing is affected along its entire span.

The increase of the effective angle of attack at portions of the wing span occupied by the ailerons will generally do no harm, but give rise to the desired increased lift, as at the same time the effective camber is increased by turning down the aileron.

But in the immediate vicinity of the aileron the effective angle of attack is increased about as much without any increase of the effective camber. Hence, if this portion was near its stalling angle it might reach it in consequence of the aileron action. The maximum increase of the effective angle of attack of the aileron reaches ordinarily 5° and more. The effective angle of attack of the wing portion near the aileron may then be about 3° for the aspect ratio chosen in the computation as shown by the diagrams. With a smaller aspect ratio $\frac{b^2}{S}$ it may even be more. Therefore, the burbling point may be reached by the displacement of the aileron. As soon as this takes place, the foundation of our method of computation is upset.

The region of burbling will then probably spread to the outside and the lateral control will be injuriously affected.

Fig. 4 shows the case of the same elliptic wing twisted linearly with α_o proportional to the distance x from the middle. This case does not require any computation, as then all factors of the Fourier's series, except $n = 2$ become zero, and the effective angle is linear again and equal to

$$\alpha_e = \frac{\alpha_g}{1 + 4\ S/b^2}$$

The consideration of the case suggests a way to remedy the danger of overstalling the wing by displacing the ailerons. The trouble lies in the sudden change of the equivalent twist of the wing given by the ailerons at its inner end. The lift curve cannot follow the sharp bend, as this would amount to finite pressure differences between adjacent points. Hence the ailerons' effect is flattened out along the span and extends to portions of the wing without flap.

This investigation, therefore, suggests the examination of such ailerons, the effect of which diminishes gradually at their inside ends, for instance, by tapering the ailerons towards inside. The The ailerons occupying a large portion of the span and a small portion of the entire wing chord might also prove advantageous in this respect. Such modifications should preferably be tried out in free flight (or else as model tests in a high pressure wind tunnel) and might prove a successful means to diminish the danger arising from loss of control at low flying speeds.

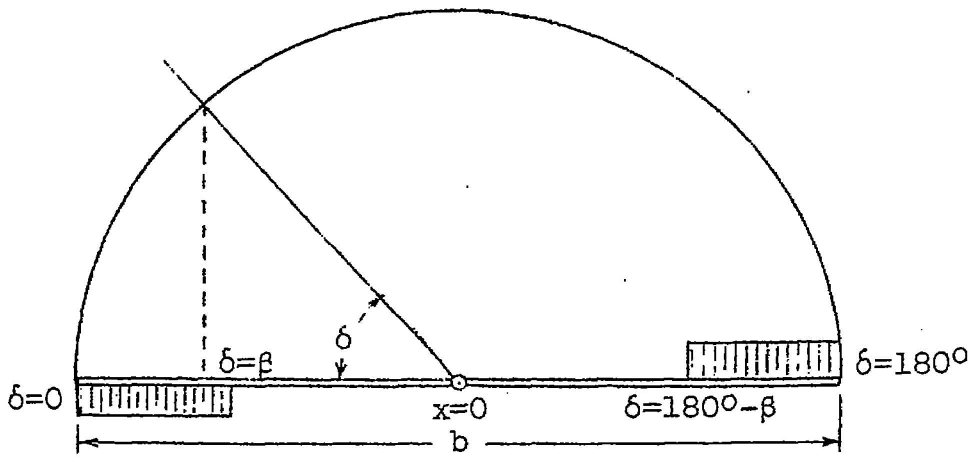

Fig. 1

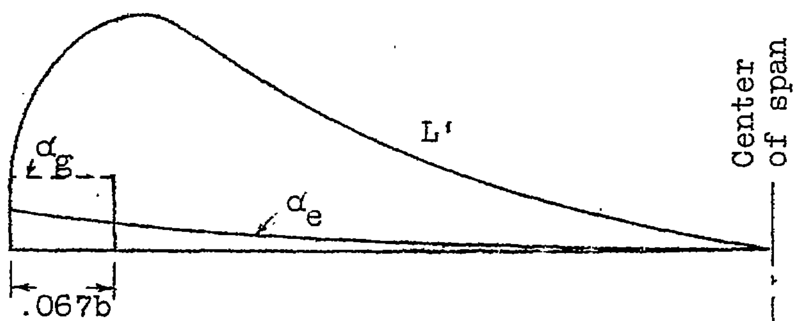

Fig. 2
β=30°

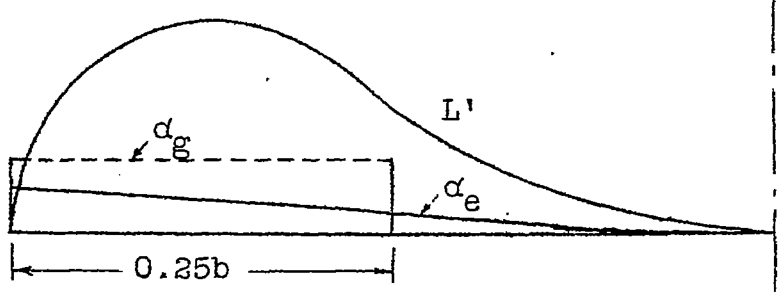

Fig. 3
β=60°

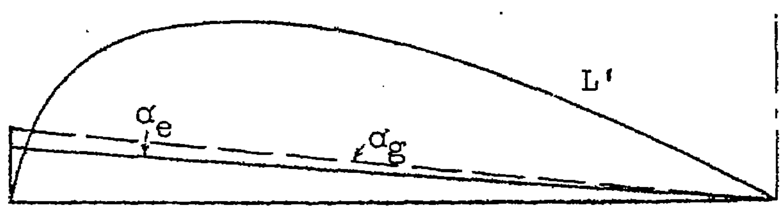

Fig. 4